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AUTOMATED COST AND SCHEDULING FOR MILITARY CONSTRUCTION: A CONCEPTUAL ALGORITHM FOR TRIAL DESIGN

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Two functional building systems were investigated: the reinforced concrete framing system and the sprinkler system. The components of each of these systems were studied, designers were interviewed, and trial design rules were elicited and analyzed.

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AUTOMATED COST AND SCHEDULING FOR MILITARY CONSTRUCTION: A CONCEPTUAL ALGORITHM FOR TRIAL DESIGN

1 INTRODUCTION

Background

The U.S. Army Corps of Engineers (USACE) is responsible for managing a huge military construction effort for the Army and Air Force. A major problem USACE faces today is that a growing need for new construction and renovation has come at a time of major reductions in the defense budget and escalating construction costs. Thus, it is essential to make optimal use of the dollars available through careful planning and systematic decision making. While USACE has always embraced such an objective, the large number of projects and limited personnel to handle the heavy workload have made this management task increasingly difficult.

The project manager's decision-making process could be enhanced if it were possible to obtain accurate estimates of construction cost and completion time in the early feasibility stage of a project. The U.S. Army Construction Engineering Research Laboratory (USACERL) is seeking to make this possible through development of a computer system for integrated cost and schedule estimation. Ideally, such an automated system could give accurate estimates when the relevant information is available. In the early stages of a project, when this information is still in the development phase, the system should be able to approximate results to be used as a base estimate for project cost and duration. As more information becomes available, the estimate will become more and more accurate.

At the early stage of a project, a trial design would be helpful in modeling the project for making the cost and time estimates. The preliminary design would provide a base for the quantity survey and consequently for estimating costs and durations. Trial design capability is envisioned as being a critical part of the automated system. Therefore, if an integrated cost and scheduling system is to become a reality, it is first necessary to determine the feasibility of developing algorithms to model the trial design. These algorithms could significantly improve the accuracy of construction costs and duration estimating at the early feasibility stage of a project.

Objective

The objective of this study is to determine the feasibility of developing algorithms for the initial trial design of different building components. Such algorithms should identify the key parameters and the design rules typically used by designers to produce the preliminary design of these components.

Approach

USACERL selected two building systems for study: a reinforced concrete framing system and a sprinkler system. For the reinforced concrete framing system, the major components addressed were the slabs, beams, and columns. For the sprinkler system,

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major components were the sprinklers, branches, cross-mains, feed-mains, and risers. Next, USACE designers were interviewed to define the key parameters used in designing each of these building components. This information was used to create sets of necessary data inputs for the algorithm and to formulate a preliminary design procedure. With this information, trial design algorithms for each component were developed and analyzed.

2 RESULTS AND ANALYSIS

The General Algorithm for Trial Design

The general algorithm for trial design is illustrated in Figure 1. The process consists of six items:

Data Inputs:
   1.   Job-specific data

Data Base:
   2.   Code and zoning knowledge
   3.   Defaults
   4.   Design practice

Processing:
   5.   Design
   6.   Quantity survey.

A brief description of each of these items follows.

Data Inputs

1. Job-Specific Data. These data identify the project and define the type of facility and its use, in addition to its size. They are the project data that are essential for the design of the element under consideration. This data will generally be at the conceptual level because the project is still at the early preliminary stage. Examples of this data may be number of bays (l and m), bay dimensions (L_x and L_y), number of floors (n), and the height of floors (h_f).

Data Base

2. Code and Zoning Knowledge. This consists of provisions set by the code to be used in designing the element, for example the live load on a slab (LL_s) and the minimum depth of the slab (d_s).

3. Defaults. The defaults consist mainly of two types: (1) material defaults, which are the material properties that will be needed in, the analysis of the element under consideration (e.g., the concrete and steel stresses, f_c and f_s, and the concrete and steel densities, μ_c and μ_s); (2) element defaults, which are the default dimensions for the element under consideration (e.g., the depth and the breadth of the beam, d_b and b_b. The main purpose of introducing element defaults is to calculate the dead load of the element and to use that as an input to the design.

The defaults should be made readily accessible by the system so that the user may change any of them according to the case under consideration.

4. Design Practice. This consists of general rules that designers use in their more common designs, for example, using factor $\phi = 0.9$ in the moment equation

$$M = \frac{wl^2}{11 \times \phi} \qquad \text{[Eq 1]}$$

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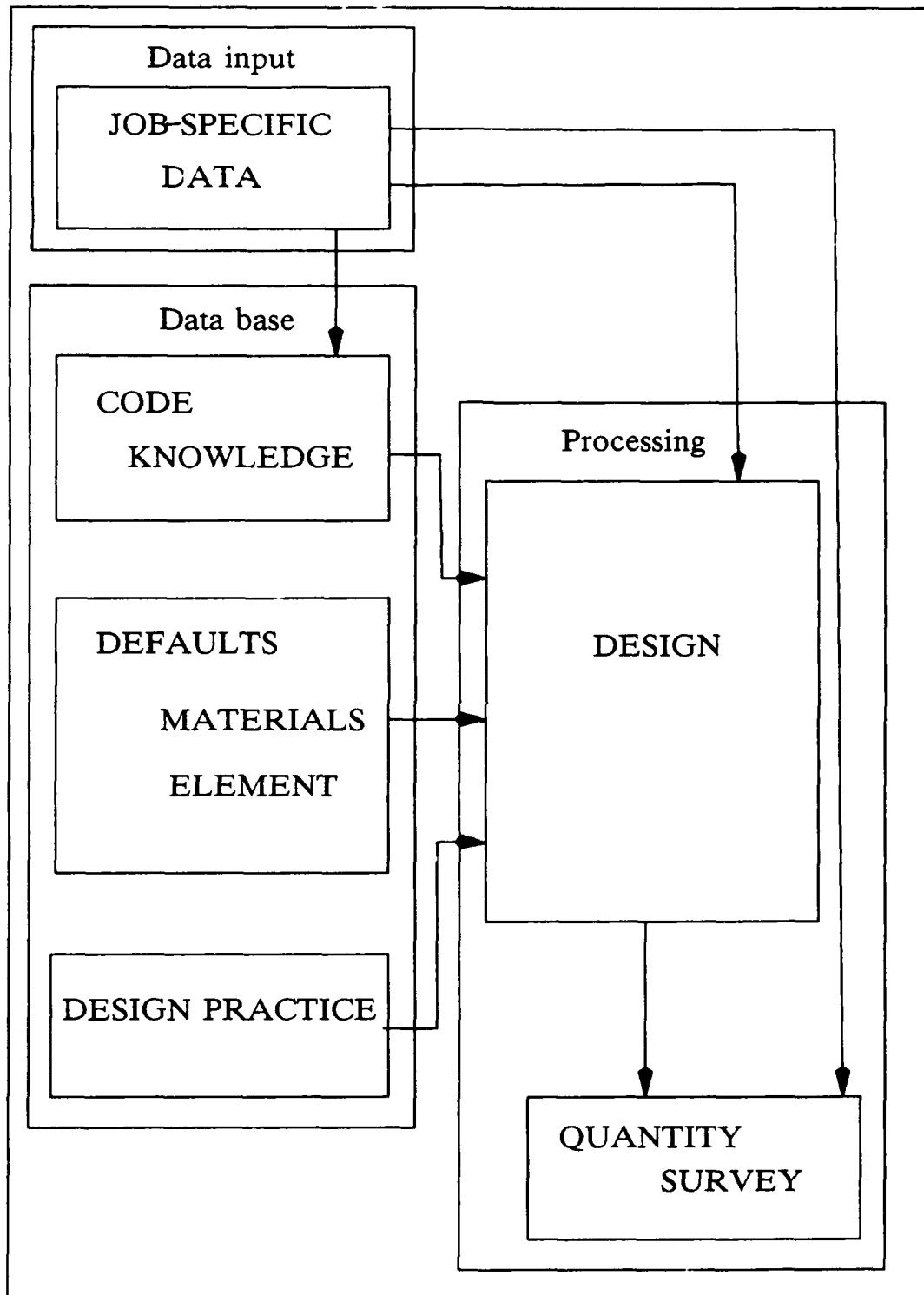
Figure 1. General algorithm for trial design.

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and using factor $k = 5$ in the slab depth equation

$$d_s = (kM_s/[f_c' \times b_s])^{1/2} \qquad \text{[Eq 2]}$$

Analysis

5. Design. This consists of the quick rules that designers use to come up with an approximate trial design for the element under consideration. For example: the temperature steel (A_{ts}) for a slab is equal to 0.18 percent of the cross-sectional area of the slab (i.e., $A_{ts} = 0.0018 \times b_s \times h_s$) and the total steel area (A_{ss}) for the slab cross section is

$$A_{ss} = \frac{M_s}{0.85\ f_s d_s} + A_{ts} \qquad \text{[Eq 3]}$$

where M_s is the moment on the slab*T*
f_s is the steel allowable stress
d_s is the depth of the slab
0.85 is a structural analysis constant
and b_s and h_s are the slab breadth and height, respectively.

The information necessary for this item (5) of the algorithm comes from the previous items (1, 2, 3, and 4). It must be noted, however, that the design rules in this item will give only approximate results because very little information is available about the structure at this stage. As more information becomes available (e.g., the drawings), these results could be updated, and thus more accurate results could be achieved. The system should also be built so that it may be easily expanded. Sophisticated design rules may be added to handle accurate detailed design, if desired, when the required information is available.

6. Quantity Survey. This item is devoted to calculating the material quantities for the element under consideration, for example, the quantities of formwork, concrete, and reinforcing steel in the slab, the beam, and the column. The information necessary for calculating these quantities comes from the first item (job-specific data) and the fifth item (design) because the quantity surveyor needs the job layout and the dimensions of the different elements. The only information which may be needed from the second item (defaults) would be the steel density (μ_s) because the reinforcing steel quantities are always displayed in weight units rather than in volume or area units.

The quantities calculated in this item (6) of the algorithm should be the base for calculating the material costs of an automated, integrated cost and scheduling system (see the *Background* section of chapter 1). They should also be the input to the other parts of the system, where crews are designed and durations are calculated. Once this is done, the labor costs of the project may be calculated, and using the activity durations, the project schedule and the project duration may be determined.

Results

This section briefly describes the components of the two systems that were tackled in this study. The components of the reinforced concrete framing system (the slabs, the

1. Job-specific data

$$Type, \quad L_x, \quad L_y$$

2. Code knowledge

$$L\,L_s, \quad minA_{ss}, \quad mind_s$$

3. Defaults

$$f'_c, \quad f_s, \quad \mu_c, \quad \mu_s$$

$$d_s, \quad b_s$$

4. Design practice

$$\phi = 0.9, \quad k = 5$$

5. Design

$$D\,L_s = \mu_c \times (d_s + 1.5)$$

$$w_s = (\;1.4 \times D.L._s$$
$$+ 1.7 \times L.L._s\;)$$

$$M_s = \frac{w_s \times L_x^2}{11 \times \phi}$$

$$d_s = \sqrt{\frac{k \times M_s}{f'_c \times b_s}}$$

$$h_s = d_s + 1.5$$

$$A_{ts} = 0.0018 \times b_s \times h_s$$

$$A_{ss} = \frac{M_s}{0.85 \times f_s \times d_s} + A_{ts}$$

6. Quantity survey

$$Formwork = L_x \times L_y$$
$$Concrete = L_x \times L_y \times h_s$$
$$Rebar = (A_{ss} \times L_x \times L_y$$
$$\times \mu_s)$$
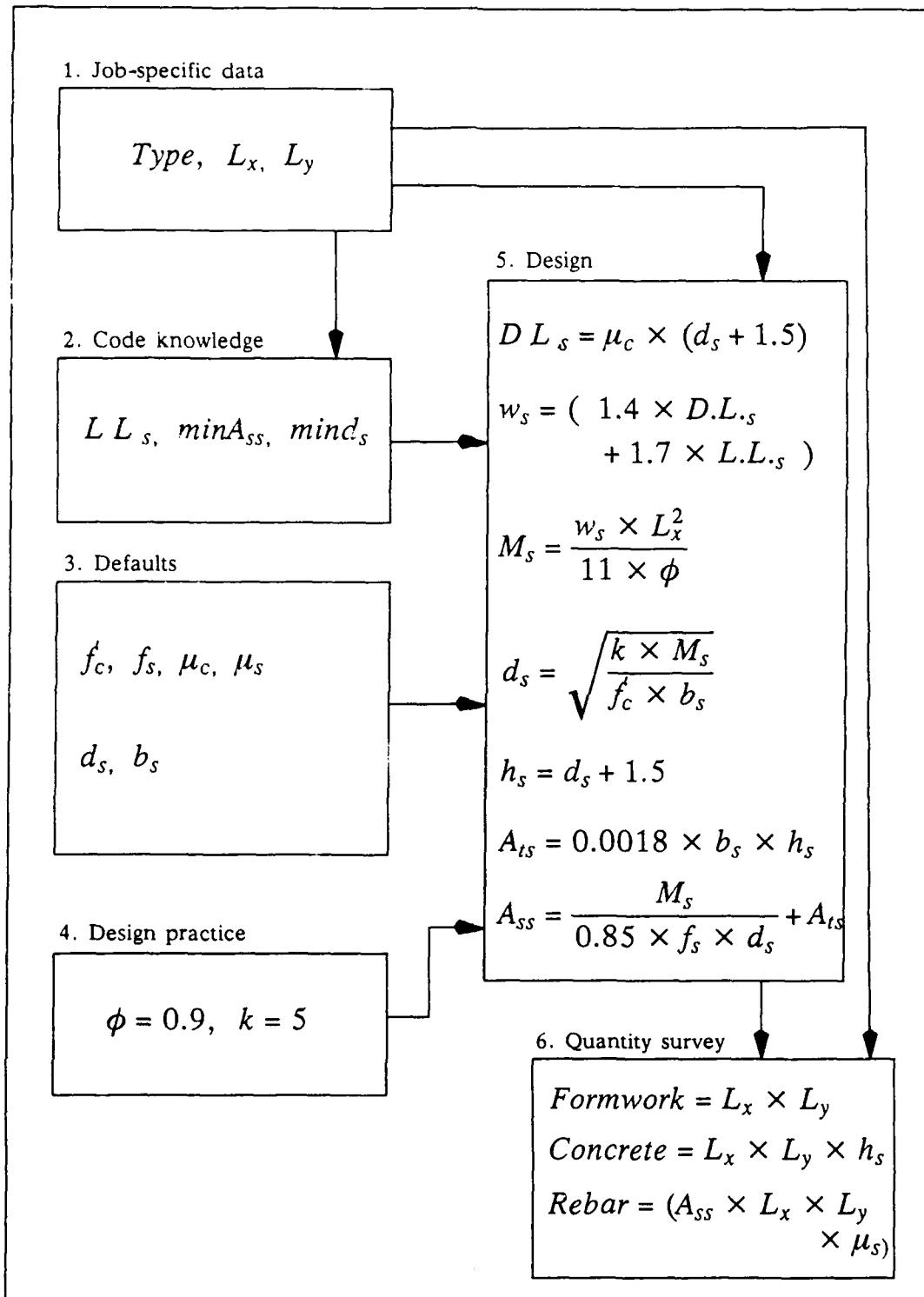
Figure 2. Trial design algorithm for the slab.

beams, and the columns) are mentioned first, followed by those of the sprinkler system (the sprinklers, the branches, the cross-main, the feed-main and the riser). For each of these components the algorithm procedure is identified, and the underlying assumptions are stated. The typical algorithm consists of six items; however, some of these items may not be required for all of the components discussed. Where an item was not required, it was deleted from the discussion.

The Slab (see Figure 2)

1. Job-specific data. The only job-specific data necessary for a slab design, in addition to the type of building which determines its use, are the bay dimensions (L_x and L_y), where L_x is the shorter dimension.

2. Code and Zoning Knowledge. This section includes provisions for the live load according to the use of the building. Provisions for the minimum slab depth and the minimum reinforcing steel area used are also included.

3. Defaults. This section includes the default values for the materials used in the job, namely, the allowable stresses and densities of the concrete and reinforcing steel, given consecutively. Default values for the slab are included and may be considered as 6 in. (15.24 cm) for the slab depth (d_s) and 1 ft (30.48 cm) for the slab breadth (b_s).

4. Practice. This includes the use of $\phi = 0.9$ and $k = 5$, which are design constants commonly used in the moment and the depth equations, respectively.

5. Design. The basic assumptions underlying the slab design are that (1) all slabs are assumed to have partial continuity and are supported by four beams for each slab, and (2) all slabs are designed as one-way slabs, with $L = x$ (the shorter side) as the design length. The design equations for the slab are shown in Figure 2. The slab is assumed to have a concrete cover of 1.5 in. (3.8 cm) and a temperature steel area of 0.18 percent of the cross section.

6. Quantity Survey. The quantities of formwork, concrete, and reinforcing steel in Figure 2 are those for one slab (one bay) only. To get those quantities for the whole building, a multiplier of l x m x n should be used where

        l = number of bays in x direction
       m = number of bays in y direction
       n = number of floors.

In the case of a building where the bays have different dimensions, then each group of adjacent bays with the same dimensions should be designed as a separate sub-building.

The Beam (see Figure 3)

1. Job-Specific Data. The only job-specific data necessary for a beam design are the bay dimensions (L_x and L_y), where L_x is the shorter dimension.

2. Code and Zoning Knowledge: This item includes provisions for the minimum steel area and the minimum depth of the beam.

3. Defaults. Material defaults include concrete and reinforcing steel allowable stresses and densities, respectively. The beam defaults may be considered as 24 in. (60.96 cm) for the depth and 6 in. (15.24 cm) for the breadth. This will allow for two adjacent beams, each with a depth of 24 in. (60.96 cm) and a breadth of 6 in. (15.24 cm).

1. Job-specific data

$$L_x, \quad L_y$$

2. Code knowledge

$$minA_{sb}, \quad mind_b$$

3. Defaults

$$f'_c, \quad f_s, \quad \mu_c, \quad \mu_s$$

$$d_b, \quad b_b$$

4. Design practice

$$\phi = 0.9, \quad k = 5$$

5. Design

$$w_b = (\ w_s \times \frac{L_x}{2} + (d_b + 1.5) \times \dot{b}_b \times \mu_c\ )$$

$$M_b = \frac{w_b \times L_y^2}{11 \times \phi}$$

$$d_b = \sqrt{\frac{k \times M_b}{f'_c \times b_b}}$$

$$h_b = d_b + 1.5$$

$$A_{sb} = \frac{M_b}{0.85 \times f_s \times d_b}$$

6. Quantity survey

$$Formwork = 4 \times (\ h_b - h_s\ ) \times (\ L_x + L_y\ )$$

$$Concrete = 2 \times h_b \times b_b \times (\ L_x + L_y\ )$$

$$Rebar = 2 \times \mu_s \times A_{sb} \times (\ L_x + L_y\ )$$
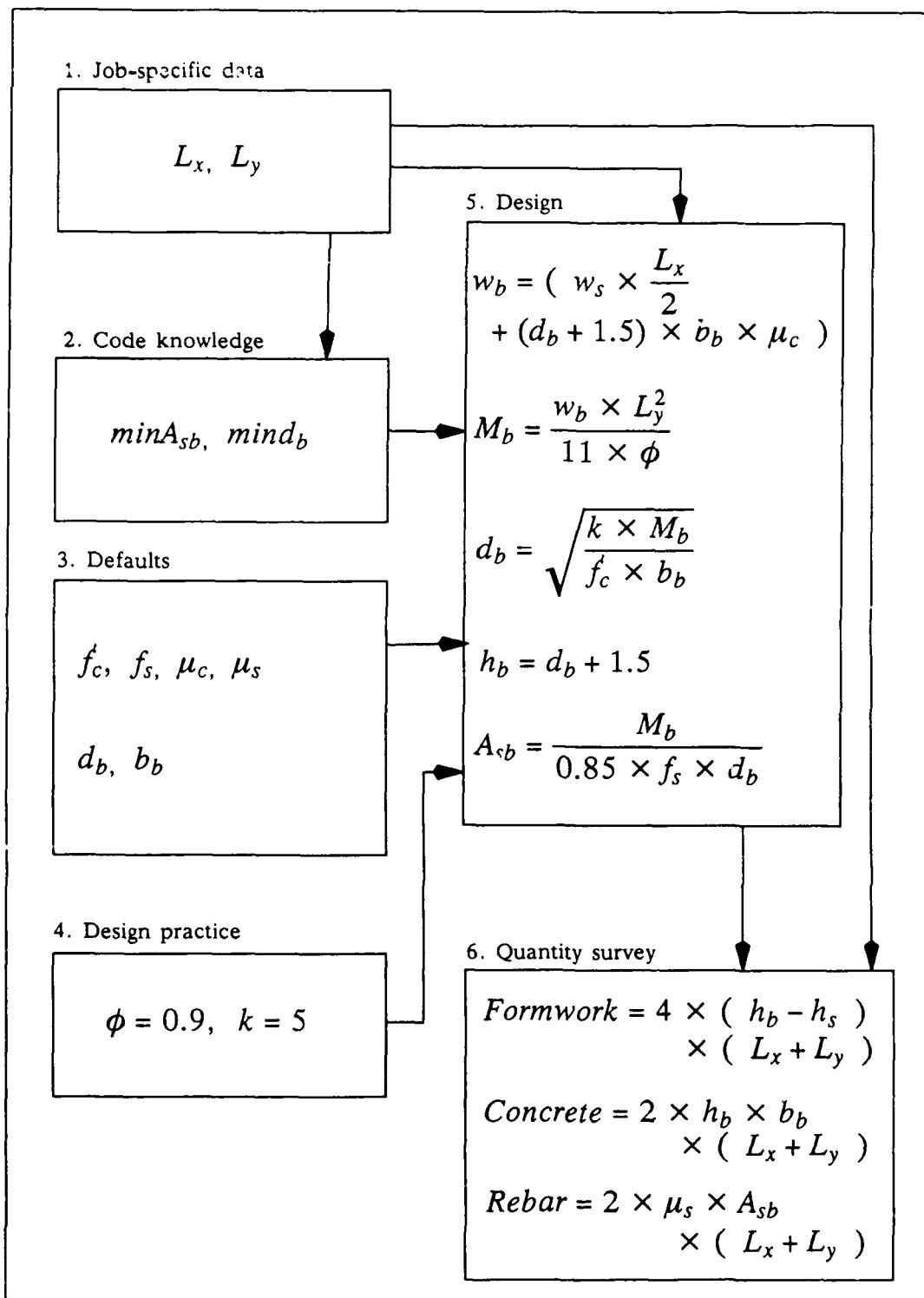
Figure 3. Trial design algorithm for the beam.

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4. Design Practice. This includes the use of ϕ = 0.9 and k = 5, which are design constants commonly used in the moment and the depth equations, respectively.

5. Design. The basic assumptions underlying the beam design are that (1) beams are assumed to have partial continuity, and (2) all beams are designed to carry one-way slabs; therefore, the design length of the beam is the longer bay dimension (L_y). The design equations for the beam are shown in Figure 3. The beam is always designed after the slab, so information is assumed to flow from the designed slab values to the beam. The total loading on the designed slab (w_s) is transferred to the beams supporting it. The beam is assumed to have a concrete cover of 1.5 in. (3.81 cm).

6. Quantity Survey. The quantities of formwork, concrete, and reinforcing steel in Figure 3 are the approximate quantities for the four beams supporting one slab (one bay). To get those quantities for the whole building, a multiplier of l x m x n (same as the slab multiplier) should be used.

The Column (see Figures 4 and 5)

1. Job-Specific Data. The job-specific data required for the column design are the bay dimensions (L_x and L_y), the number of floors (n), and the height of the floors (h_f).

2. Code and Zoning Knowledge. This includes provisions for the minimum cross-sectional area of the column as well as the minimum steel reinforcement used.

3. Defaults. The material defaults include the concrete and the reinforcing steel allowable stresses. In Figure 5, values for these defaults are inserted. A value of 4 ksi is used for the concrete stress, a value of 60 ksi is used for the reinforcing steel stress, and a value of 0.225 ksi is used for the total weight on the slab, where the dead load is assumed to be 0.1 ksi and the live load is assumed to be 0.05 ksi.

4. Design. The basic assumptions underlying the column design are that (1) exterior columns and interior columns are assumed to carry the same loads, (2) all columns are assumed to have a square cross section, (3) the weights of the columns themselves are neglected in the design, and (4) the column at the middle floor of the building is the one being designed and is assumed to run from the top to the bottom of the building. The design equations for the column are shown in Figures 4 and 5. The main difference between these two figures is that Figure 4 shows the basic equation of the column design with the variables included in the equation. In Figure 5, the variables are substituted for their default values shown in the figure, and a simpler equation is derived. The column is assumed to have a steel area of 1 percent of its cross-sectional area.

6. Quantity Survey. The quantities of formwork, concrete, and reinforcing steel in Figures 4 and 5 are those for one column only. To get the quantities for the whole building, we need a multiplier of (l + 1) x (m + 1) x n.

The Sprinklers (see Figure 6)

1. Job-Specific Data. The job-specific data required for the design of the sprinklers are the bay dimensions (L_x and L_y), the number of bays in both directions (l and m), the floor height (h_f) and the number of floors (n) in addition to the building type, which determines the degree of hazard according to its use.

1. Job-specific data

$$L_x, \ L_y, \ n, \ h_f$$

2. Code knowledge

$$minA_{sc,} \ minA_c$$

3. Defaults

$$f'_c, \ f_s$$

4. Design practice

5. Design

$$A_c = \frac{w_s \times (\ L_x + L_y \ )}{0.005f_s + 0.43f'_c} \times \frac{n+1}{2}$$

$$A_{sc} = 0.01 \times A_c$$

6. Quantity survey

$$Formwork = 4 \times \sqrt{A_c} \times h_f$$

$$Concrete = A_c \times h_f$$

$$Rebar = A_{sc} \times h_f \times \mu_s$$
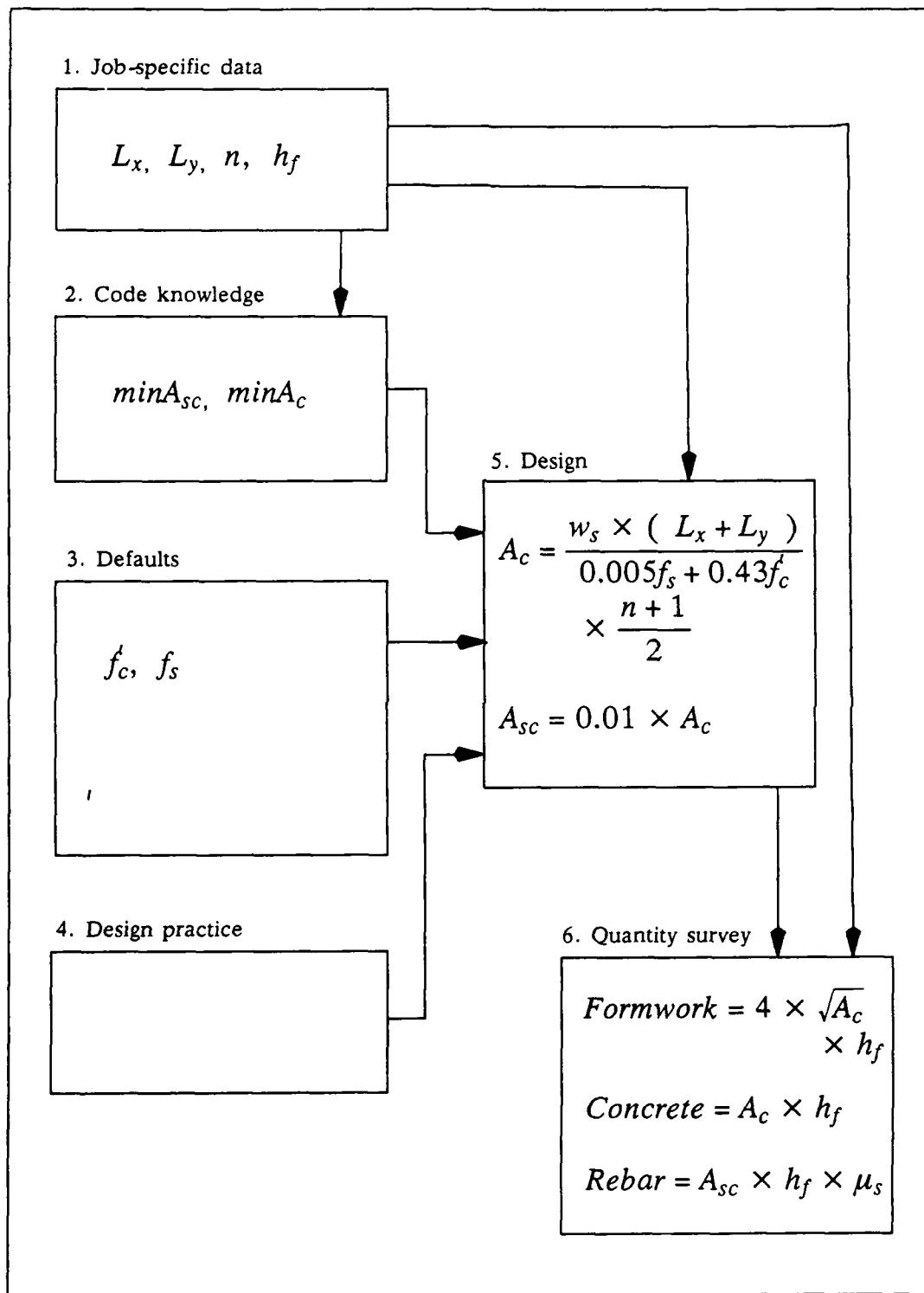
Figure 4. Trial design algorithm for the column.

1. Job-specific data

$$L_x, \ L_y, \ n, \ h_f$$

2. Code knowledge

$$minA_{sc}, \ minA_c$$

3. Defaults

$$f'_c = 4, \ f_s = 60,$$
$$w_s = 0.225$$

4. Design practice

5. Design

$$A_c = \frac{L_x \times L_y}{9} \times \frac{n+1}{2}$$

$$A_{sc} = 0.01 \times A_c$$

6. Quantity survey

$$Formwork = 4 \times \sqrt{A_c} \\ \times h_f$$

$$Concrete = A_c \times h_f$$

$$Rebar = A_{sc} \times h_f \times \mu_s$$
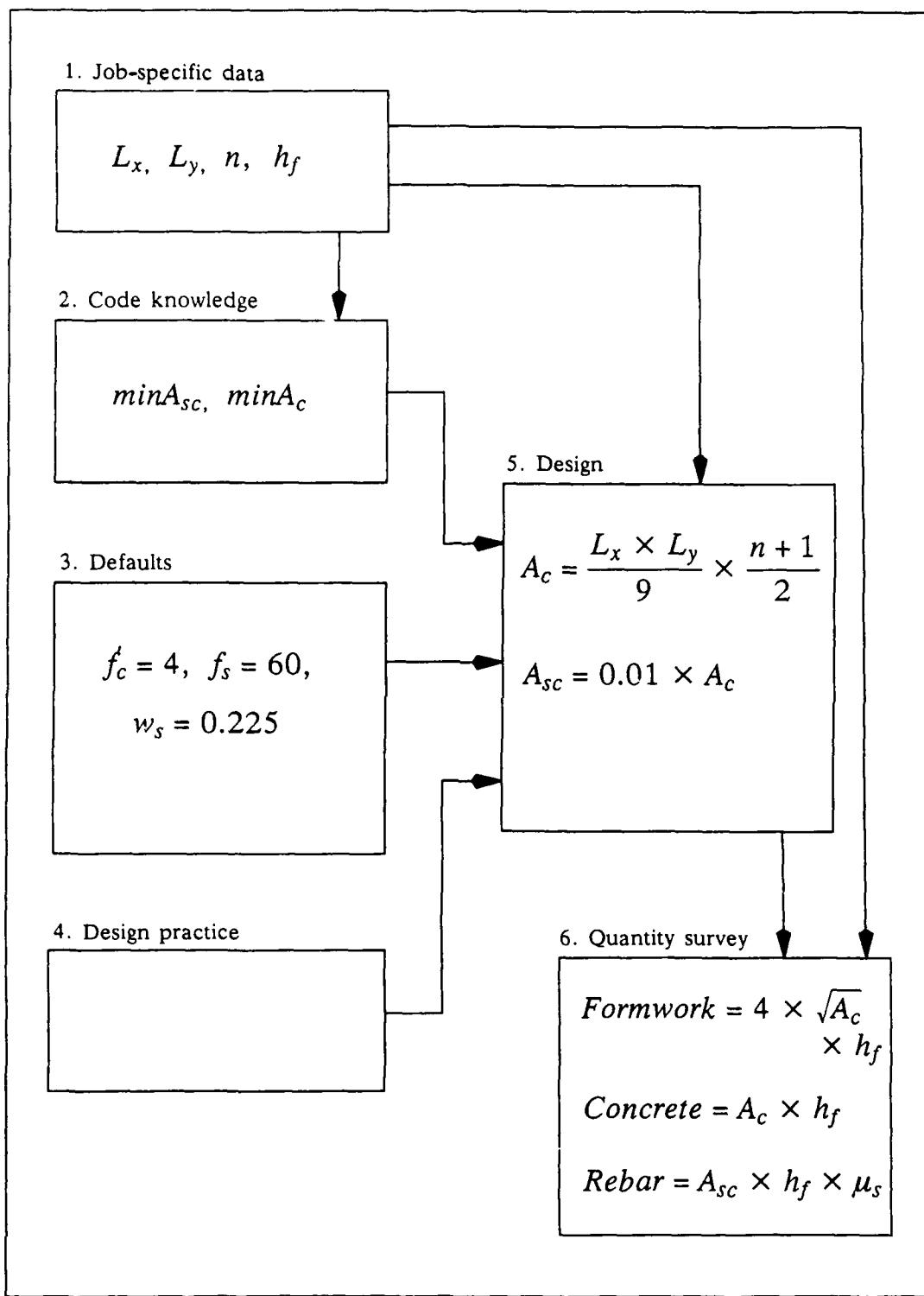
Figure 5. Trial design algorithm for the column (simplified).

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1. Job-specific data

$Type,\ L_x,\ L_y,\ h_f,$
$l,\ m,\ n$

2. Code knowledge

$s_s,\ S$

3. Defaults

4. Design practice

5. Design

$$n_s = Larger\ (\ \frac{L_x \times L_y}{S}$$

$$OR$$

$$Integer(\ \frac{L_x}{s_s}\ ) + 1$$
$$\times$$
$$Integer(\ \frac{L_y}{s_s}\ ) + 1\ )$$

6. Quantity survey

$$N_s = n_s \times l \times m \times n$$
$$N_j = n_s \times l \times m \times n$$
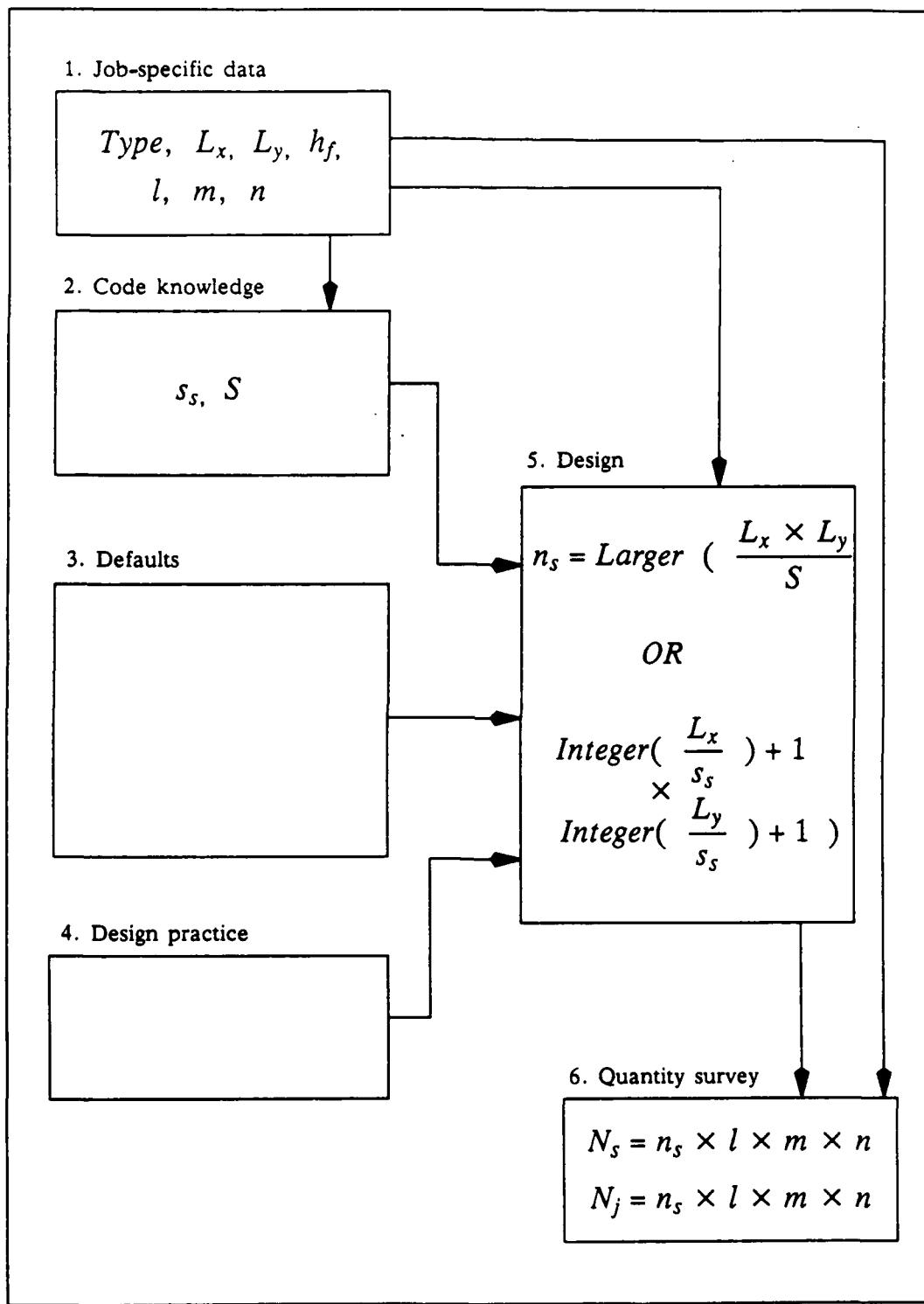
Figure 6. Trial design algorithm for the sprinklers.

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2. Code and Zoning Knowledge. This includes provisions for the maximum spacing between the sprinklers (s_s) and the maximum area protected by one sprinkler (S) according to the degree of hazard of the building.

5. Design. The number of sprinklers in one bay (n_s) is designed to satisfy the two provisions set by the code, namely, the maximum allowable area protected by one sprinkler and the maximum allowable distance between the sprinklers.

6. Quantity Survey. The total number of sprinklers (N_s) and joints (N_j) shown in Figure 6 are those for the whole building serviced by one riser.

The Branches (see Figure 7)

1. Job-Specific Data. The job-specific data required for the design of the branches are the bay dimensions $(L_x$ and $L_y)$, the number of bays in both directions (l and m) and the number of floors (n) in addition to the building type, which determines the degree of hazard according to its use.

2. Code and Zoning Knowledge. This includes provisions for the minimum pipe size and the maximum allowable spacing between the branches (s_b) according to the degree of hazard of the building.

3. Practice. This includes the common practice of spacing the hangers (s_h) for the branches at 7 ft (2.13 m) distances.

5. Design. The branches are assumed to be designed parallel to the shorter side of the building. After determining the shorter dimension, the integer number of branches is calculated for each bay and then multiplied by the number of bays to get the number of branches on one floor (b).

6. Quantity Survey. The length of branches (L_b) shown in Figure 7 is that for the whole building serviced by one riser, and so is the number of hangers and joints calculated.

The Cross-Main (see Figure 8)

1. Job-specific data. The job-specific data required for the design of the cross-main are the bay dimensions $(L_x$ and $L_y)$, the number of bays (l and m), and the number of floors (n).

2. Code and Zoning Knowledge. This includes provisions for the minimum pipe size.

4. Practice. This includes the common practice of spacing the hangers (s_h) for the cross-main at 7 ft (2.13 m) distances.

5. Design. The cross-mains are designed parallel to the longer side of the building. Each floor in the building has one cross-main $(N_c = 1)$. The term "building" here implies the whole building or the part of the building which is serviced by one riser.

6. Quantity Survey. The quantities shown in Figure 8 are those for the whole building serviced by one riser.

1. Job-specific data

$$Type, \quad L_x, \quad L_y,$$
$$l, \quad m, \quad n$$

2. Code knowledge

$$Pipe\ size, \quad s_b$$

3. Defaults

4. Design practice

$$s_h = 7$$

5. Design

$$If\ (L_x \times l > L_y \times m)$$

$$then\ b = l \times (Integer(\ \frac{L_x}{s_s}\ ) + 1)$$

$$else\ b = m \times (Integer(\ \frac{L_y}{s_s}\ ) + 1)$$

6. Quantity survey

$$L_b = Smaller\ (L_x \times l$$
$$OR\ L_y \times m) \times b \times n$$
$$N_h = Integer\ (\ \frac{L_b}{s_h}\ ) + 1$$
$$N_j = b \times n$$
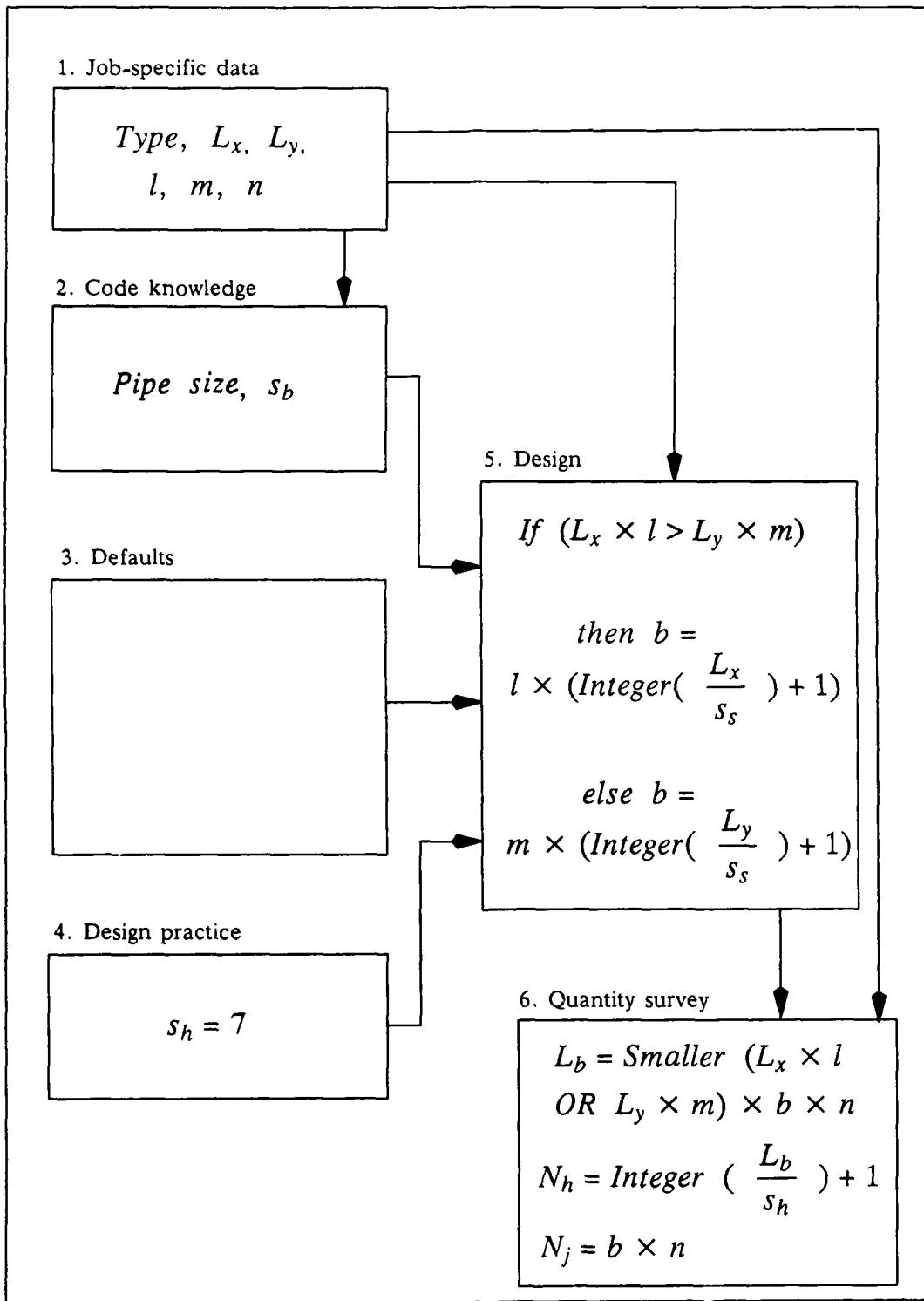
**Figure 7. Trial design algorithm for the branches.**
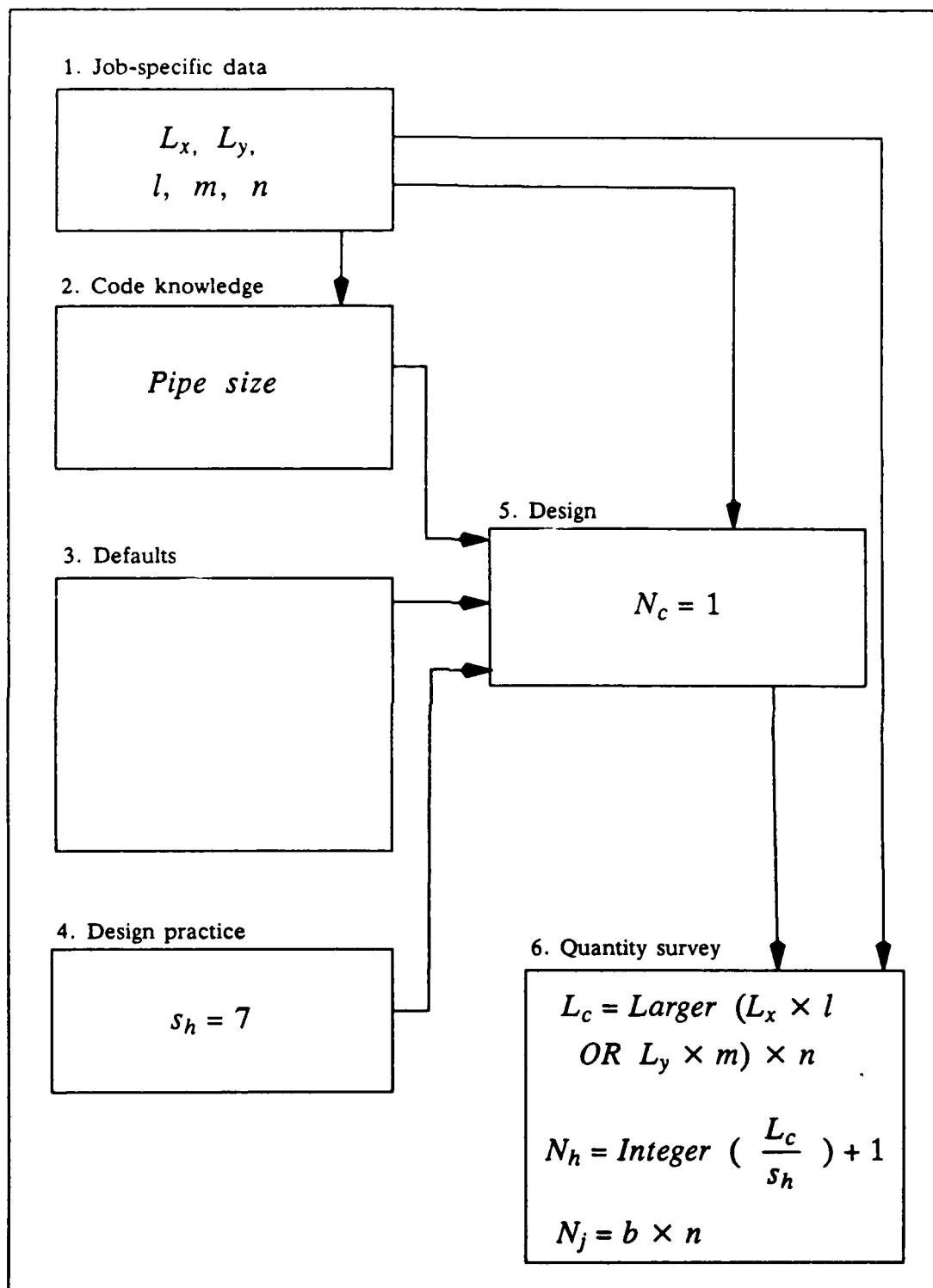
Figure 8. Trial design algorithm for the cross-main.

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The Feed-Main (see Figure 9)

    1. Job-Specific Data. The job-specific data required for the design of the feed-main are the bay dimensions (L_x and L_y), the number of bays (l and m), and the number of floors (n).

    2. Code and Zoning Knowledge. This includes provisions for the minimum pipe size.

    4. Practice. This includes the common practice of spacing the hangers (s_h) for the feed-main at 7 ft (2.13 m) distances.

    5. Design: The feed main is designed to be parallel to the shorter side of the building. Each floor in the building has one feed-main ($N_f = 1$). The term "building" here implies the whole building or the part of the building which is serviced by one riser.

    6. Quantity Survey. The quantities shown in Figure 9 are those for the whole building serviced by one riser.

The Riser (see Figure 10)

    1. Job-Specific Data. The job-specific data required for the design of the riser are the bay dimensions (L_x and L_y), the number of bays (l and m), the number of floors (n), and the floor height (h_f) in addition to the building type, which determines the degree of hazard according to its use.

    2. Code and Zoning Knowledge. This includes provisions for the maximum allowable floor area (F) that is serviced by one riser according to the degree of hazard of the building. Provisions for the minimum pipe size are also included.

    4. Practice. This includes the common practice of using one hanger at the base of the riser.

    5. Design: The riser is designed to be placed at the longer side of the building. Each sprinkler system has only one riser. The building may, however, have more than one sprinkler system and thus more than one riser, depending on the maximum floor area that can be serviced by one riser. In the case where more than one riser is used, then the floor area serviced by each riser would be considered as a separate building or sub-building, and the sprinkler system components would be designed for that sub-building.

    6. Quantity Survey. The quantities shown in Figure 10 are those for the building serviced by one riser.

Analysis

    The data and the algorithms in this study have been based on a limited sample of designers. Nevertheless, it was clear from the sample that designers use the general algorithm when required to conduct an initial trial design at the early feasibility stage of a project. Some of the items not designed by the designers, yet needed by the contractors, are not included in the study (e.g., slab shoring). Obviously, these items would be included in the complete system.

1. Job-specific data

$$L_x,\ L_y,$$
$$l,\ m,\ n$$

2. Code knowledge

$$Pipe\ size$$

3. Defaults

4. Design practice

$$s_h = 7$$

5. Design

$$N_f = n$$

6. Quantity súrvey

$$L_f = Smaller\ (\ \frac{L_x \times l}{2}$$
$$OR\ \frac{L_y \times m}{2}\ ) \times n$$

$$N_h = Integer\ (\ \frac{L_f}{s_h}\ )\ + 1$$

$$N_j = 2 \times n$$
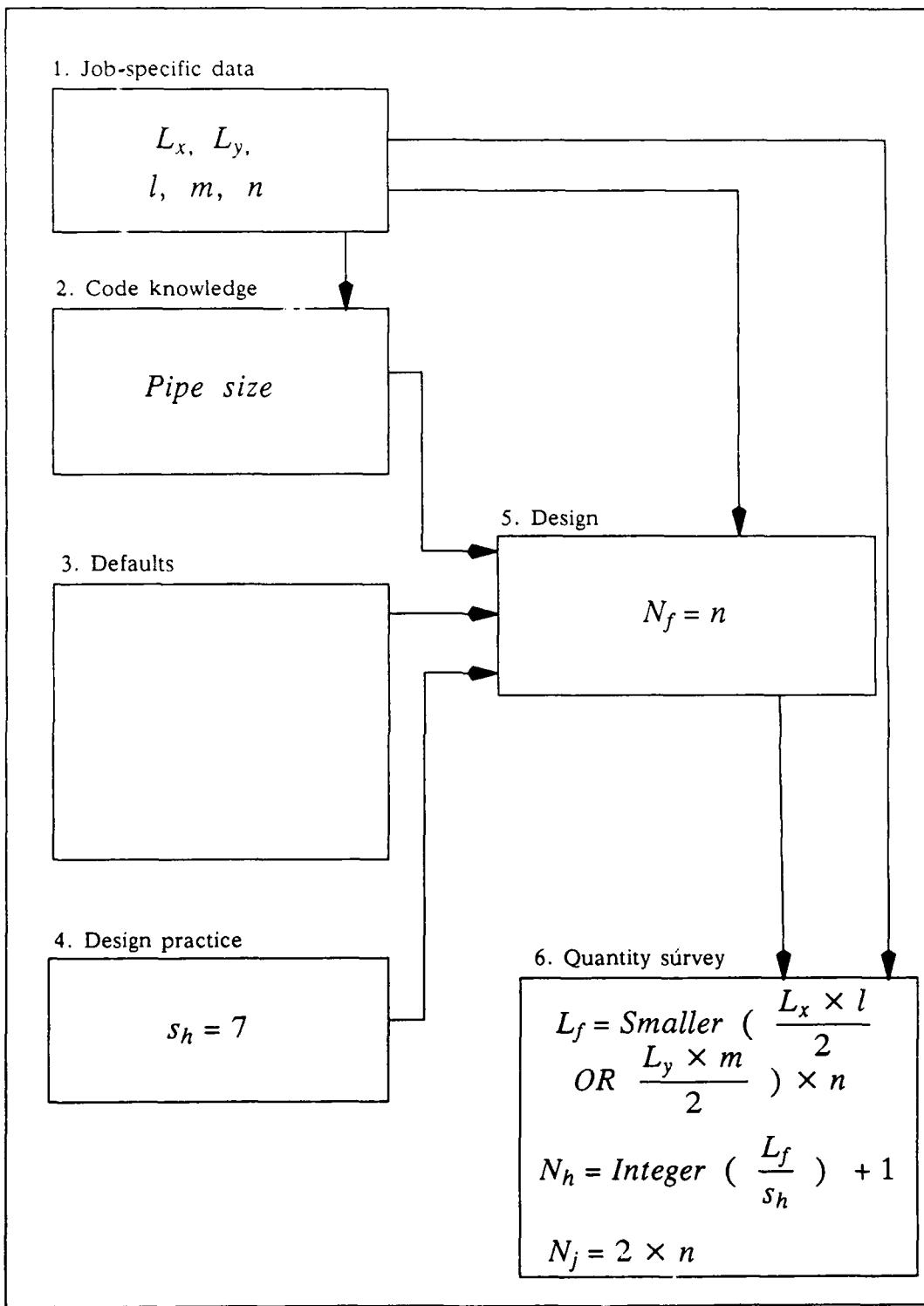
Figure 9. Trial design algorithm for the feed-main.

1. Job-specific data

$Type,\ L_x,\ L_y,$
$l,\ m,\ n,\ h$

2. Code knowledge

$Pipe\ size,\ F$

3. Defaults

4. Design practice

$n_h = 1$

5. Design

$r = Integer\ ($
$\dfrac{L_x \times l \times L_y \times m}{F}\ )\ + 1$

6. Quantity survey

$L_r = n \times h$

$N_h = n + 1$
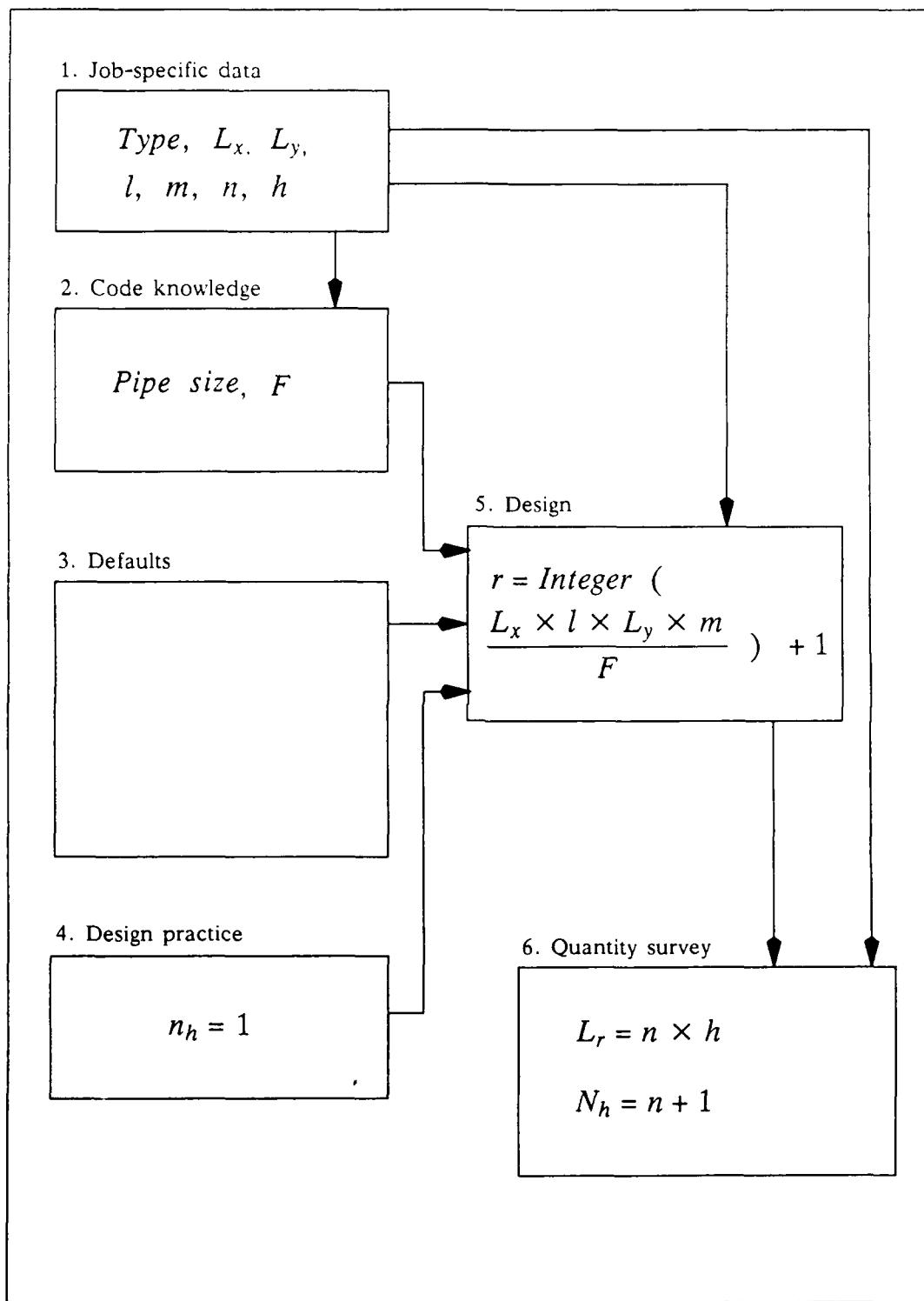
Figure 10. Trial design algorithm for the riser.

As was observed from the study, the information required for this design was very crude because it deals with the project while it is still at the conceptual level. This information consisted mainly of the number of bays and their sizes and the number of floors and their heights, in addition to the type and use of the building.

The algorithm for the reinforced concrete framing system developed in this study was tested on an existing facility (a 7-story library building). The design dimensions and the reinforcing steel areas for the slabs, the beams and the columns were calculated using the algorithm and were compared to the actual dimensions. Table 1 shows such a comparison for a typical slab, a typical beam, and a typical column.

Obviously, the simplified formula did not work for the columns in this building. One of the main reasons is the dead load and live load assumptions of 0.1 ksi and 0.05 ksi in the simplified formula, which would be extremely low for a library building. However, the results for slabs and beams seem quite satisfactory.

The sprinkler system algorithm developed in this study was then tested on two existing facilities. The first facility was a hotel, which was divided into five buildings, four of which had two floors and the fifth had three floors. The algorithm was applied to each building, and the number of sprinklers was calculated. Table 2 shows the results of applying the algorithm compared with the actual number of sprinklers.

The second facility was a laboratory consisting of three floors. The algorithm was applied to this building twice: First, the building was considered a light-hazard building and, second, it was considered an extra-hazard building. The algorithm results are compared with the actual results for both cases. Results seem to conform with the extra hazard design.

Because developing trial design algorithms for the components of a concrete framing system (the slab, the beam, and the column) appears feasible, it is reasonable to assume that algorithms can be developed for other systems, such as the components of the steel framing system and those of the foundations. By the same token, the sprinkler system sets an example for other systems or subsystems, such as the various components of the mechanical and electrical systems. Each of these components can be broken down into subsystems, and algorithms for these components can be developed.

Table 1

Algorithm Versus Actual Measurement: Slab, Beam, Column

	Algorithm	Actual
Slab height	6 in. (15.24 cm)	6 in. (15.24 cm)
Slab-reinforcing steel area	0.628 in.^{2} (4.05 cm^2)	0.653 in.^{2} (4.21 cm^2)
Beam height	24.39 in. (61.95 cm)	24 in. (60.96 cm)
Beam-reinforcing steel area	2.154 in.^{2} (13.89 cm^2)	2.07 in.^{2} (13.35 cm^2)
Column cross-sectional area	448 in.^{2} (2889.6 cm^2)	216 in.^{2} (1393.2 cm^2)
Column-reinforcing steel area	4.48 in.^{2} (28.89 cm^2)	2.64 in.^{2} (17.03 cm^2)

Using the simplified column equation in Figure 5, the results were

	Algorithm	Actual
Column cross-sectional area	60 in.^{2} (387 cm^2)	216 in.^{2} (1393.2 cm^2)
Column-reinforcing steel area	0.6 in.^{2} (3.87 cm^2)	2.64 in.^{2} (17.03 cm^2)

Table 2

Algorithm Versus Actual Number of Sprinklers per Building

	Algorithm	Actual
Number of sprinklers in Bldg. 1	88	88
Number of sprinklers in Bldg. 2	81	80
Number of sprinklers in Bldg. 3	64	64
Number of sprinklers in Bldg. 4	88	88
Number of sprinklers in Bldg. 5	120	120

Table 3

Algorithm Versus Actual Number of Sprinklers: Light Hazard, Extra Hazard

	Algorithm	Actual
Number of sprinklers (light hazard)	446	1017
Number of sprinklers (extra hazard)	900	1017

3 CONCLUSIONS AND RECOMMENDATIONS

A trial design algorithm was developed for designing building components at the early feasibility stage of a project. Two systems were addressed in this study, the reinforced concrete framing system and the sprinkler system of a building. Both algorithms were tested on existing facilities, and results were quite satisfactory. It therefore appears likely that similar design algorithms for other building components could be successfully developed.

Time and resource constraints prevented testing the algorithms on a number of facilities in order to further validate the results. Moreover, these constraints prevented the performance of an in-depth study of other systems which appeared to conform to the general process addressed in this study.

Further study in this area should include interviewing designers to obtain more detailed information for various building systems. Such systems as plumbing, heating, electrical, steel framing, and foundations seem to be good candidates for such an expansion. With further study, assumptions may be tied to specific building types and components rather than to a single generic preliminary design calculation. Another possible extension to this system would be to integrate design code requirements with building criteria which can automatically choose the appropriate design formula directly from building codes.

It would also be beneficial to do further testing in order to evaluate the limitations of the algorithms developed so far and to apply this procedure to the development and validation of future systems.

NOTATION

L_x	=	the shorter bay dimension
L_y	=	the longer bay dimension
h_f	=	height of floor
l	=	number of bays in x direction
m	=	number of bays in y direction
n	=	number of floors
f'_c	=	concrete allowable stress
f_s	=	steel allowable stress
ama_c	=	concrete density
ama_s	=	steel density
d_s	=	depth of slab
b_s	=	breadth of slab
h_s	=	height of slab
LL_s	=	live load on slab
DL_s	=	dead load on slab
w_s	=	total load on slab
A_{ss}	=	area of steel in slab cross section
M_s	=	moment on slab
A_{ts}	=	area of temperature steel in slab
b_b	=	breadth of beam
d_b	=	depth of beam
h_b	=	height of beam
A_{sb}	=	area of steel in beam cross section
w_b	=	total load on beam
M_b	=	moment on beam
K, ϕ	=	design constants
A_c	=	cross-sectional area of column
A_{sc}	=	area of steel in column cross section
F	=	maximum floor area serviced by one riser
r	=	number of risers
s_s	=	maximum allowable spacing between sprinklers
s_b	=	maximum allowable spacing between the branches of a sprinkler system
n_s	=	number of sprinklers in one bay
b	=	number of branches in one floor of a sprinkler system

S = maximum allowable area protected by one sprinkler

N_s = number of sprinklers in building

N_h = number of hangers in building

N_c = number of cross-mains in one floor

N_f = number of feed-mains in one floor

N_j = number of joints

L_b = length of the branch pipes in a building

L_c = length of the cross-main pipes in a building

L_f = length of the feed-main pipes in a building

L_r = length of the riser pipes in a building

n_h = number of hangers in one floor connected to riser

s_h = spacing between the hangers in a sprinkler system